https://doi.org/10.17895/ices.pub.8515

ICES Marine Science Symposia, 215: 124–131. 2002

Martin Knudsen - the oceanographer

Jens Smed

Smed, J. 2002. Martin Knudsen – the oceanographer. – ICES Marine Science Symposia, 215: 124–131.

Martin Knudsen was introduced to hydrography (i.e., physical oceanography) when, at a young age, he was appointed to undertake the physical and chemical investigations on the Danish "Ingolf" expedition in 1895 and 1896 to the waters around Iceland and western Greenland. He was a Danish Delegate to the Stockholm Conference, which entrusted him with the task of an experimental revision of the existing hydrographical tables. This work resulted in Knudsen's Hydrographical Tables, used the world over for three-quarters of a century. Knudsen introduced the use of standard seawater for salinity determinations, and was in charge of the Standard Seawater Service from 1908 to 1948. He designed new versions of instruments, such as burettes, pipettes, reversing thermometers, water bottles, and bottom samplers. Knudsen was attached to ICES Headquarters from 1902 to 1948 in various capacities: Hydrographical Assistant, editor, Hydrographic Consultant, and Chef du Service Hydrographique. He was a Danish Delegate to the Council during 1902–1947, Vice-President during 1933–1947, and Chair of the Hydrography Committee from its establishment in 1925 until 1947.

Keywords: hydrographical tables, instruments, Martin Knudsen, standard seawater.

Jens Smed: Bygtoften 17, DK–2800 Lyngby, Denmark; tel: +45 45 87 11 01.

Introduction

Martin Knudsen's scientific work was spread over two branches of science: physics and hydrography (i.e., physical oceanography). As a physicist, he was attached to the University of Copenhagen and the Polytechnical College of Denmark from 1896 to 1941 in the capacity as assistant, lecturer, and, from 1912 to 1941, professor. He was an expert who was highly esteemed internationally on the kinetic theory of gases, especially on their behaviour at low pressures. In hydrography, Knudsen became a pioneer in salinity determination because of his Hydrographical Tables and his responsibility during a long period of years for the preparation of standard seawater. For nearly half a century, he was connected with ICES in various capacities: Hydrographer, Delegate, Chair of the Hydrography Committee, and member of the Bureau.

Martin Knudsen's introduction to hydrography

Martin Knudsen was introduced to hydrography when he was appointed to undertake the physical and chemical investigations on the Danish "Ingolf" expedition to the waters around Iceland and western Greenland in the summers of 1895 and 1896 (Figure 1). As he declared in his report on the hydrographical work of the expedition (Knudsen, 1899a), until that time he had been totally unacquainted with that type of research. Nevertheless, he did outstanding work. Knudsen's talent for designing instruments became apparent. He developed an apparatus for analysis of the gases held in seawater and designed an improved version of the reversing thermometer.

He was also aware of the importance of more exact salinity determinations, as it had become clear that dissimilar water masses might differ only slightly in salinity, sometimes by not more than the inaccuracy inherent in most of the previous salinity determinations. Knudsen, therefore, rejected the method of determining salinity from measuring specific gravity. Instead, he determined the chlorine (or rather halogen) content of the water samples by means of volume titration according to the Mohr method, i.e., precipitation of the chlorine with a solution of silver nitrate, using potassium chromate as an index. In order to increase the accuracy of the method, Knudsen introduced sealed tubes of seawater whose salinity had been determined with great care by a Volhard titration; this water was then employed to calibrate the silver nitrate used for the titration of the water samples. In this way, all chlorine determinations were referred to the same standard and resulted in internal consistency. The salinity value was obtained by multiplying the chlorine content or chlorinity by the so-called coefficient of chlorine. While processing the data

Figure 1. Martin Knudsen in the laboratory of the cruiser "Ingolf." Courtesy of the Zoological Museum, Copenhagen.

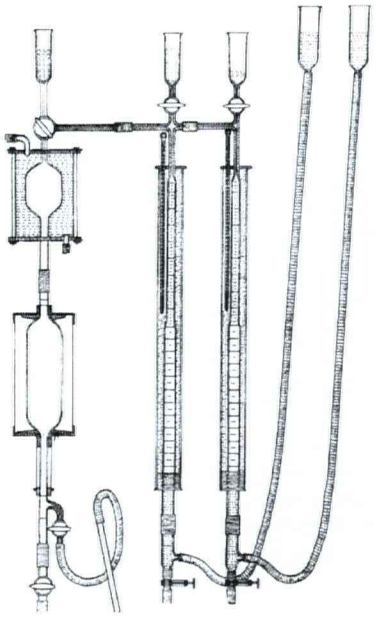

Figure 2. Knudsen's apparatus for determination of the content of oxygen and nitrogen in seawater.

from the "Ingolf" expedition, Knudsen also prepared tables facilitating calculation of the specific gravity of a seawater sample from its temperature and salinity.

An important part of the shipboard hydrographic work was the determination of the amounts of dissolved gases in the water. Knudsen constructed an apparatus for simultaneously measuring the amounts of nitrogen and oxygen in a sample of seawater (Figure 2). With regard to oxygen, Knudsen found some apparent anomalies. It was generally assumed that surface water was just saturated with air, in accordance with the temperature of the water. In the material from the "Challenger" expedition, however, William Dittmar had found some samples with more oxygen than was consistent with the laws of gas absorption. He had tried to account for the apparent anomaly in a variety of ways, but was at last led to suggest that the anomaly might be the result of observational errors (Dittmar, 1884). Hercules Tornøe, in working up the material from the Norwegian "Vøringen" expedition, encountered the same problem. He, however, was not inclined to accept observational errors as the explanation. He concluded that the amount of oxygen in surface water depended not only on the temperature of the water, but also on the effect of one or more causes as yet unknown (Tornøe, 1880).

On the "Ingolf" expedition, Knudsen also found a number of cases of oxygen supersaturation in surface water and was able to solve the mystery. He conceived the idea that the phenomenon might be due to oxygen production by phytoplankton photosynthesis and confirmed this assumption by investigating, in cooperation with the expedition's botanist, C. H. Ostenfeld, the type and amount of plankton at the locations where the water samples were collected. It turned out that oxygen content was low where zooplankton were dominant, but high where phytoplankton predominated. Some simple experiments by Knudsen corroborated that supersaturation of oxygen in the upper water layers might indeed be explained from phytoplankton photosynthesis (Knudsen, 1896). In this way, the results that had puzzled Dittmar and Tornøe became understandable.

The Hydrographical Tables

Knudsen's achievements on the "Ingolf" expedition and in working up hydrographic data from inner Danish waters were eminent. It was, therefore, natural that he, in spite of his young age (born 1871), became one of the three Danish Delegates to the International Conference

for the Exploration of the Sea at Stockholm in 1899. Here he received favourable attention, as suggested by an internal German report on the Conference (Krümmel, 1899).

Knudsen's experience from the "Ingolf" expedition led him to propose to the Conference that an international institution for procuring standard seawater should be established (Knudsen, 1899b). Although recognizing the importance of using standard seawater for salinity determinations, the Conference did not adopt the proposal. It preferred a plan submitted by the Norwegian Delegate Fridtjof Nansen that, in connection with the Central Office of the new organization, there should be a Central Laboratory which, i.a., should produce and distribute standard seawater (Nansen, 1899).

The favourable decision on Nansen's proposal did not imply a lack of confidence in Knudsen. This is evident from the fact that the Conference entrusted him with the task of an experimental revision of the existing hydrographical tables, viz. his own from the "Ingolf" expedition as well as those compiled by Krümmel, Makarov, and others. The idea for such a revision came from Otto Pettersson. In a letter to Nansen, Pettersson had deplored the lack of reliable tables giving the relation between the chemical analysis of seawater and its specific gravity. So if there were a conference about an international exploration of the sea, Pettersson intended to propose the appointment of a committee for the investigation and revision of all existing tables in order to clarify the correspondence of a specific gravity value in chemical analysis. Pettersson thought this investigation should be conducted in the laboratory of the Polytechnical College in Copenhagen under the direction of Martin Knudsen (Pettersson, 1898). A committee, consisting of Sir John Murray, Knudsen, Pettersson, Nansen, Otto Krümmel, H. N. Dickson, and S. O. Makarov, was appointed to direct the work which was organized by Knudsen and carried out at the physical laboratory of the Polytechnical College where Knudsen was on the staff. He was assisted mainly by the Danish J. P. Jacobsen and S. P. L. Sørensen, and the German Carl Forch. Knudsen, with his collaborators, determined the constants of seawater, i.e., the relation between chlorinity and salinity, and between chlorinity and specific gravity of the water at different temperatures. These constants formed the basis for the preparation of the famous Hydrographical Tables which permitted an accurate determination of the chlorine content, salinity, and specific gravity of a seawater sample from a Mohr titration against standard seawater. Tables of salinity and specific gravity were also included on the basis of hydrometer readings. The determination of the constants and the elaboration of the Hydrographical Tables represented a formidable task which was carried out by Knudsen and his small team in less than two years.

The Tables and a report on the work were presented at the second International Conference for the Exploration of the Sea at Kristiania (Oslo) in May 1901. The Conference gave its blessing to the Tables, deciding that:

> The ratios between salinity, density and chlorine given in Dr. Martin Knudsen's Hydrographical Tables are to be adopted; and the salinity is to be calculated by use of these Tables from the determinations of chlorine or from the specific gravity (Anon., 1901).

Even though the work had been undertaken with utmost care, there are indications, as pointed out by Wallace (1974), that Knudsen considered his salinity– chlorinity equation only a temporary measure which a new study might change. There was a preponderance of non-oceanic samples in the material used, with 15 of the 26 samples coming from the North Sea and the Baltic, and all except two were surface samples. Accordingly, it was felt that there might be a need for a study consisting of more oceanic samples and with more time at its disposal. Regardless, Knudsen's equations and his Tables were used worldwide for nearly three quarters of a century. During this long period, the equation and the Tables generally remained unchallenged, except for some doubt about their reliability expressed by a couple of laboratories soon after their appearance. The doubt, however, turned out to be unjustified (Smed, 1992).

The Standard Seawater Service

The Stockholm Conference had decided that there was a need for a standard seawater to be used in chlorine titrations and that it should be produced by the Central Laboratory. Martin Knudsen foresaw that the establishment of the Laboratory would take some time. In order to bridge the gap during this period, he decided to prepare a batch of such water. It should be remembered that the preparation of standard water was nothing new to Knudsen. Even before the Stockholm Conference, he had made five batches for use in Danish hydrographic work. Consequently, the standard water prepared for use in the determination of constants for the revision of the existing tables was designated No. VI. The chlorinity of this standard water was determined by the chemist S. P. L. Sørensen on the basis of a sample of potassium chloride. All subsequent standards were based, therefore, on the chlorine content of this sample of potassium chloride and consequently depended on the atomic weights then adopted.

As surmised by Knudsen, there was a clear need for standard water even if international cooperation had not yet been established. Several institutions in the prospective Member Countries of the International Council obtained samples, and the demand increased when the seasonal cruises agreed upon at Stockholm were begun in 1902. As the Central Laboratory was not yet fully established, Knudsen had to prepare one more batch of standard water. From 1903, the Central Laboratory took over production, including the preparation of a Primary Standard in 1905. Knudsen was apparently somewhat

Figure 3. Bottling of standard seawater in Copenhagen.

disappointed that he had not been entrusted with the Standard Seawater Service. In a letter to Otto Pettersson, who had complained about the delay in preparation of the Primary Standard at the Central Laboratory, Knudsen declared that since the Laboratory had been entrusted with the preparation of standard seawater, he assumed that this was considered to be of more concern to the Laboratory than to him, and that the Laboratory could do it better than he (Knudsen, 1903).

In 1908, however, it was decided to close down the Central Laboratory and assign most of its tasks to the national laboratories. But it was felt that there was one practical charge that was of interest to all hydrographers, viz. the preparation of standard seawater. The Council decided to delegate this task to Martin Knudsen in his capacity as Hydrographical Assistant to the Bureau (ICES, 1909). So, during the following years until the outbreak of World War I in 1914, the standard seawater was prepared by Knudsen under the authority of the Council. At that time, Knudsen took over the Standard Seawater Service in a personal capacity in order to relieve the Council of the financial responsibility during the war, an arrangement that also continued after the war. There was increasing demand for standard water and, in the 1930s, the stock of the Primary Standard from 1905 used for determining the salinity of ordinary standard seawater was running low. It therefore became necessary to prepare a new Primary Standard. At the Council meeting in 1936, Knudsen explained that since the standard water was used worldwide, he intended to propose to the International Association for Physical Oceanography (IAPO) that it should direct the preparation of a new Primary Standard and defray the expenses connected with the physical and chemical work and the publication of a report. This was agreed by ICES and accepted by IAPO (Anon., 1937).

The chlorinity of the new Primary Standard 1937 was determined by comparison with the chlorinities of the standard water samples hitherto used, thereby achieving conformity with the results of the chlorinity titrations based upon the two Primary Standards. The chlorinity was found to be 19.3810 ‰. It was pointed out, however, that the chlorinity, as defined by Sørensen, depended on the adopted values of the atomic weights. This meant that there would be slight breaks in the chlorinity determinations when new values of atomic weights were agreed upon. Also, a tube of seawater was probably not the best standard if continuity were to be maintained over a long time period. These drawbacks were remedied by choosing pure silver, so-called *Atomgewichtssilber*, as the standard and introducing a new definition of chlorinity. Investigations carried out by Professor Hönigschmid in Munich indicated that 58.99428 grams of *Atomgewichtssilber* were necessary and sufficient to precipitate the halogens in one kilogram of the Primary Standard 1937. As 19.3810/ 58.99428 = 0.3285234, the new definition of chlorinity became:

> The number giving the chlorinity in per mille of a seawater sample is by definition identical with the number giving the mass with unit gram of *Atomgewichtssilber* just necessary to precipitate the halogens in 0.3285234 kilogram of the seawater sample (Jacobsen and Knudsen, 1940).

When Knudsen was in his late seventies, anxious to ensure the continuation of the Standard Seawater Service, he proposed to IAPO that it should assume responsibility for the future preparation of standard seawater. This was accepted by IAPO in August 1948 (Anon., 1949), with the work still to be done in the Danish Hydrographical Laboratory (Figure 3). In February 1949, Knudsen distributed a circular about the new arrangement. A few months later, he passed away. However, because of the arrangement with IAPO (later IAPSO), the Service continued (Figure 4).

Designing of instruments

During the "Ingolf" expedition, Knudsen, in addition to designing a more reliable version of the reversing thermometer and constructing an apparatus for analysis of air dissolved in seawater, also introduced improved types of pipettes (Knudsen, 1897) and burettes which greatly facilitated the chlorine titration and became used worldwide. Because of these improvements by Knudsen, his introduction of standard water, and his Hydrographical Tables, the chlorine titration of seawater became universally known as the Mohr-Knudsen titration.

In 1898, the Commission for Scientific Investigation of the Danish Waters invited Knudsen to develop a method for measuring temperature and salinity of seawater *in situ*. He fulfilled this request by developing an

Figure 4. Tube of standard seawater.

instrument which made it possible to determine salinity and temperature of seawater without collecting water samples or removing the thermometer from the water (Knudsen, 1900). The instrument was especially suitable for determining the depth of the discontinuity layer, which is so pronounced in Danish waters. Though the method aroused considerable interest, it did not really come into use. There apparently were technical difficulties, for instance, with regard to compensation for capacity and energy loss in the cable between the submerged part of the apparatus and the shipboard instrumentation (Smed, 2002).

During a roughly 10-year period beginning in 1909, Knudsen concentrated on work in pure physics, especially on the laws of the molecular movements in gases at low pressure, and published a series of papers on these subjects. It is understandable, therefore, that he did not find time to develop new oceanographic instruments. In 1916, however, he was approached by the Danish marine biologist Johannes Schmidt, who was anxious to continue his search for the spawning area of the European eel and was planning a great expedition which would be launched when World War I was over. During the expedition, Schmidt intended to measure the penetration of light into the sea at different latitudes and in different types of water. He expressed the hope that Knudsen would take an interest in this matter and consider constructing suitable instruments. This application inspired Knudsen to begin work on determining the absorption of light in seawater. In 1922, he published his spectrophotometer together with some results obtained by means of the instrument (Knudsen, 1922).

Knudsen also designed new types of already existing instruments (Knudsen, 1923). For example, his insulating water bottle (Figure 5) was a further development of the Pettersson-Nansen bottle, but was considerably shorter, and easier to handle. Knudsen also introduced a simpler closing mechanism for the bottle. In his instruments, Knudsen aimed at simplicity in construction, compactness, and reliability in use. This is clearly evident in his reversing water bottle and even more so in its frameless version (Figure 6), designed with a view to using a number of such instruments on the wire at the same time. New types of meter wheels were also made as well as new types of weights or messengers used for releasing reversing water bottles and other instruments.

For the quantitative study of the amount of fish food at the sea bottom, the director of the Danish Biological Station, C. G. J. Petersen, had constructed a bottom sampler which he developed into the widely used Petersen grab. As Petersen admitted, however, this apparatus was unsuitable for use on hard sandy bottom where the samples were probably not representative. Knudsen therefore decided to construct a bottom sampler for hard bottom to be used as a supplement to the Petersen grab (Knudsen, 1927). The Knudsen bottom sampler (Figure 7) worked satisfactorily, penetrating about 30 cm into firm sandy bottom.

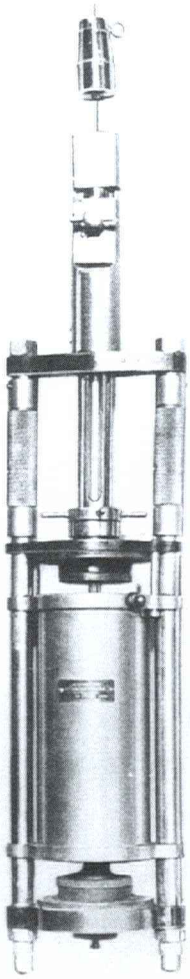

Figure 5. Knudsen's insulating water bottle.

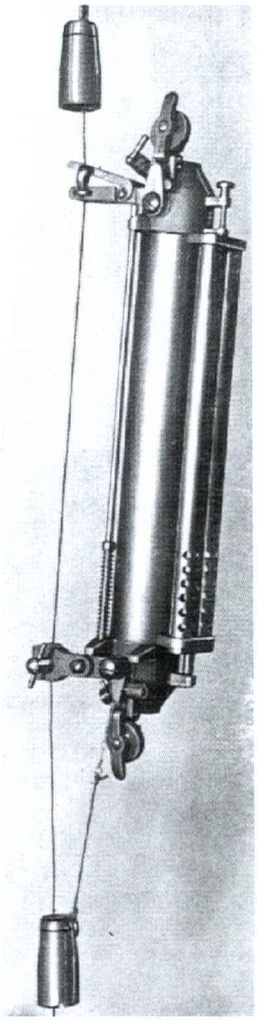

Figure 6. Knudsen's frameless reversing water bottle.

Work at the ICES Service Hydrographique

During the long period from 1902 to 1948, Martin Knudsen was closely connected with ICES. When the organization was formally established, the Council decided that its Central Office in Copenhagen should have, in addition to a General Secretary, two principal assistants for hydrography and biology, respectively. In view of his earlier achievements, it was natural that Martin Knudsen should be chosen to fill the post of Hydrographical Assistant. In this capacity, he was chief of the Hydrographic Department of the Office, the Service Hydrographique. The main hydrographic activities of the Member Countries in an ICES context during the first years of the organization were the seasonal cruises to a number of fixed stations. The hydrographic data from these cruises, together with surface observations from a number of ship routes, were sent to the Service Hydrographique and published in quarterly, and later annual, bulletins edited by Knudsen. In this way, a unique hydrographic data bank was established at ICES, available to the international scientific community and used by Knudsen and his collaborators for the preparation of charts and sections showing the distribution of temperature and salinity in the seas investigated.

Knudsen was re-elected Hydrographical Assistant each year until 1920. At this time, the war years had greatly slowed the activities of the Council. As a consequence, it was decided to elect, instead of two principal assistants, three editors for hydrography, plankton, and fishery statistics, with the editing of the corresponding bulletins to be entrusted to their care. Knudsen continued as editor of the *Bulletin Hydrographique*. As an interim arrangement for a short period (1925–1928), the

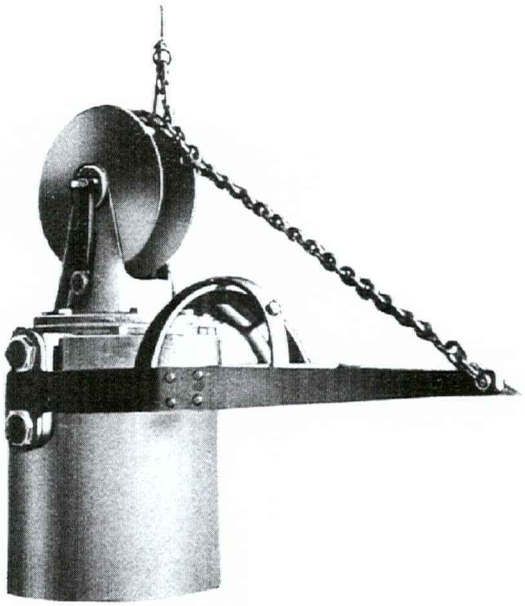

Figure 7. Knudsen's bottom sampler for hard bottom.

Council appointed a temporary Hydrographer, whereas Knudsen acted as Hydrographic Consultant. When a permanent Hydrographer was appointed in 1928, Knudsen was invited to become Chief of the Service Hydrographique and thus be responsible for the general supervision of its work. This arrangement continued until Knudsen asked to be released from his post in 1948 at the age of 77.

Another linkage between the Knudsen family and ICES was through Knudsen's daughter, Inger Bondorff. She had been deeply involved in the meticulous titrations carried out in connection with the preparation of the Primary Standard 1937, working for some time in the laboratory of Professor Otto Hönigschmid in Munich (Jacobsen and Knudsen, 1940). Inger came to the Service Hydrographique in 1952. Her main task was the preparation of the Monthly Synoptic Charts of Temperature and Salinity, but she also did most of the technical drawings for the working groups and the Secretariat. Another type of work in which she participated and acquired much skill involved screening the hydrographic data received for inclusion in the ICES data bank. Inger retired in 1986, but maintained an interest in ICES nearly until her death in 1997. So there was a linkage between the Knudsen family and ICES throughout most of the 20th century.

Epilogue

It is amazing how much Martin Knudsen (Figure 8) achieved in his lifetime. During nearly half a century, he held posts as assistant, lecturer, or professor of physics at the University of Copenhagen and the Polytechnical College of Denmark. As mentioned earlier, his research in pure physics was highly regarded. He became a member of the Royal Danish Academy of Sciences and Letters from 1909 and was its Secretary from 1917 to 1945. He was Rector of the University of Copenhagen for a period, and was an eminent organizer and administrator, to the benefit of many societies.

Knudsen was a member of the Danish Commission for the Study of the Sea and leader of the Commission's Hydrographical Laboratory from 1902 to 1948. At ICES, Knudsen held many posts. In addition to being on the staff of the Central Office, he was a Danish Delegate to the Council during the period 1902–1947, and during 1933–1947 was a Vice-President. Knudsen chaired the Council's Hydrography Committee from its inception in 1925 until 1947. Besides all of these duties, he found time for the hydrographic work reported in this paper. Martin Knudsen died on 27 May 1949.

Figure 8. Martin Knudsen (1871–1949).

Acknowledgements

I am greatly indebted to Dr Artur Svansson for valuable discussions on the manuscript and for his assistance in its processing.

References

Anonymous. 1901. 2. Conférence Internationale pour l'Exploration de la Mer Réunie à Kristiania 1901, Première Partie, p. 5.

Anonymous. 1937. Association Internationale d'Océanographie Physique, Procès-Verbaux, 2: 52.

Anonymous. 1949. Association Internationale d'Océanographie Physique, Procès-Verbaux, 4: 58.

Dittmar, W. 1884. Report on researches into the composition of ocean-water collected by H.M.S. "Challenger" during the years 1873–1876. *In* Report on the Scientific Results of the Voyage of H.M.S. "Challenger". Physics and Chemistry, I: 139–230.

ICES. 1909. Rapports et Procès-Verbaux des Réunions du Conseil Permanent International pour l'Exploration de la Mer, 11(B): 16–18.

Jacobsen, J. P., and Knudsen, M. 1940. Urnormal 1937 or Primary Standard Sea-Water 1937. Association d'Océanographie Physique, Publications Scientifiques, 7. 38 pp.

Knudsen, M. 1896. De l'influence du plankton sur des quantités d'oxygène et d'acide carbonique dissous dans l'eau de mer (On the influence of plankton on the quantities of oxygen and carbonic acid in seawater). Comptes rendus des séances de l'Académie des Sciences, 123: 1091–1093. (In French).

Knudsen, M. 1897. Pipette zum raschen und genauen Abmessen von Flüssigkeiten (Pipette for fast and accurate measuring of liquids). Chemiker-Zeitung, 21(64). (In German).

Knudsen, M. 1899a. Hydrography. The Danish "Ingolf"-expedition, 1: 23–161.

Knudsen, M. 1899b. Proposal about an international institution for procuring Standard Water. Conférence Internationale pour l'Exploration de la Mer, Réunie à Stockholm 1899, Supplément 4.

Knudsen, M. 1900. Maaling af Havvandets Temperatur og Saltholdighed ved Hjælp af elektrisk Telefonbro (Measurement of the temperature and salinity of seawater by means of an electrical telephone bridge). Beretning fra Kommissionen for videnskabelig Undersøgelse af de danske Farvande, 2(3). (In Danish).

Knudsen, M. 1903. Letter of 31 December 1903 to Otto Pettersson. Archived in Gothenburg University Library's Collection of Letters. (In Danish).

Knudsen, M. 1922. On measurement of the penetration of light into the sea. Publications de Circonstance du Conseil International pour l'Exploration de la Mer, 76.

Knudsen, M. 1923. Some new oceanographical instruments. Publications de Circonstance du Conseil International pour l'Exploration de la Mer, 77.

Knudsen, M. 1927. A bottom-sampler for hard bottom. Meddelelser fra Kommissionen for Havundersøgelser, Serie: Fiskeri, VIII(3).

Krümmel, O. 1899. Bericht über die Ergebnisse der internationalen Konferenz zur Erforschung der nordeuropäischen Meere in Stockholm 15 bis 23 Juni 1899 (Report on the results of the International Conference for the Exploration of the North European Seas in Stockholm 15 to 23 June 1899). Appended to letter of 5 August 1899 to the Minister der geistlichen Unterricht und Medizinalangelegenheiten, Berlin. Rep. 76-VC, Sekt. 1, Tit. 11, Nr. 11, Bd. 1, Blatt 275–285. Archived in Geheimes Staatsarchiv Preussischer Kulturbesitz, Berlin. (In German).

Nansen, F. 1899. Appendix 2 to Résolutions textuelles. Conférence Internationale pour l'Exploration de la Mer, Réunie à Stockholm 1899.

Pettersson, O. 1898. Letter of 29 October 1898 to F. Nansen. Archived in the Oslo University Library's Collection of Manuscripts, File 48. (In Swedish).

Smed, J. 1992. Early discussions and tests of the validity of Knudsen's Hydrographical Tables. Historisch-Meereskundliches Jahrbuch, 1: 77–86.

Smed, J. 2002. Early attempts at determination of the salinity of seawater from measurement of its electric conductivity. *In* Oceanographic History: The Pacific and Beyond. Papers from the 5th International Congress on the History of Oceanography, 369–373. Ed. by K. R. Benson and P. F. Rehbock. University of Washington Press, Seattle and London.

Tornøe, H. 1880. On the air in seawater. *In* The Norwegian North-Atlantic Expedition 1876–1878. Chemistry, 1–23.

Wallace, W. J. 1974. The development of the chlorinity/salinity concept in oceanography. Elsevier Oceanography Series, 7: 148.